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DISTRIBUTION AND COMMUNITY ASSOCIATIONS OF CAPE IVY (*DELAIREA ODORATA*) IN CALIFORNIA

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ABSTRACT

Cape ivy (*Delairea odorata* Lem.) was found to occur throughout coastal California and southern Oregon. It was most abundant in urbanized coastal areas such as the San Francisco Bay, and Santa Cruz, Monterey, San Luis Obispo, Santa Barbara and Los Angeles counties. Field observations showed Cape ivy to occur in seven different broad community types, including both riparian and non-riparian areas. Of the two morphological forms, the exstipulate type occurred more frequently at the northern and southern ends of the distribution, and the stipulate type was more common in the middle of the distribution range, from southern Humboldt County to Los Angeles County. Only 21 locations were found that supported both stipulate and exstipulate plants, and they were most often located in urbanized coastal areas. Analysis with GIS determined the elevation, temperature and precipitation ranges that Cape ivy occupies in California. The analysis indicated that Cape ivy occurs at elevations between 0 and 891 meters, annual mean temperatures between 10.5 and 17.7°C, and in areas with annual precipitation ranging between 232 and 2270 mm. An overlay analysis of Cape ivy locations using GIS was also compared with the California Natural Diversity Database sensitive species location information to determine which species might be threatened by Cape ivy expansion. Three sensitive animals and five sensitive plants were expected to have >40% of their occurrences with a 500 m buffer to Cape ivy infestations.

Key Words: German Ivy, invasive, *Senecio mikanioides*, South Africa, weed.

INTRODUCTION

Cape ivy (*Delairea odorata* Lem., syn. *Senecio mikanioides* Walp.) (Asteraceae) is native to South Africa, but has escaped cultivation to invade wildlands in Europe, Australia, New Zealand, Hawaii, and South America, as well as coastal regions of western North America (Parodi 1959; Abrams and Ferris 1960; Palhinha 1974; Zangheri 1976; Pignatti 1982; Haselwood and Motter 1983; Hirano 1983; Webb et al. 1988; Fagg 1989; Jacobi and Warshauer 1992; Scott and Delfosse 1992; Hickman 1993; Gallo 2000; DiTomaso and Healy 2007). It was first collected in California in 1892 (*F.T. Bioletti s.n.* UC36003), and since that time has spread to all coastal counties and many adjacent inland sites (Jepson 1951; Abrams and Ferris 1960; Thomas 1961; Hoover 1970; Howell 1970; Munz 1974; Smith 1976; Beauchamp 1986; Smith and Wheeler 1992; Hickman 1993; Best et al. 1996; Junak et al. 1995; Matthews 1997). Cape ivy's spread into undisturbed wildland areas of California is of great concern, particularly because effective control is difficult (Alvarez 1997; Bossard et al. 2000). Although Cape ivy has firmly established itself along California's coast, the question remains as to whether it has occupied the full extent of its potential range.

To date, only one California study has documented the community types invaded by Cape ivy within the state (Alvarez and Cushman 2002). Alvarez and Cushman (2002) compared the effect of Cape ivy on invaded and un-invaded coastal scrub, and willow and alder riparian communities. Their results showed that plots invaded by Cape ivy had a 31, 88, and 92% decrease in species diversity, abundance of native seedlings, and non-native seedlings, respectively, compared to uninvaded sites of the same community types.

In this study, we provide a map of the current distribution, as well as more detailed information on the plant community types occupied by Cape ivy. In addition, we identify the distribution of the two morphological forms of Cape ivy in California, a stipulate and exstipulate type. The results provided here will help identify threatened community types or sensitive species in proximity to Cape ivy infestations.

MATERIALS AND METHODS

Mapping

The California Exotic Pest Plant Council (now known as the California Invasive Plant Council, Cal-IPC) Cape Ivy Working Group began collecting Cape ivy distribution data in 1995. In May 1995, the distribution of Cape ivy was mapped along streams and hillsides in the coastal region of California, south of Monterey Co. (no vouchers taken). Additionally, appropriate habitats such as lakes, campgrounds, and parks along the coast were also surveyed. All populations that were reported by Cal-IPC members, California Native Plant Society (CNPS) members, park rangers, and other concerned citizens were visited, confirmed, and described for future analysis. The boundaries of the populations were estimated and drawn on maps. The data collected were then digitized as point data on 1:100,000 topographic base maps using MapInfo Professional 5.0 (LizardTech, Seattle, WA).

Additional areas were surveyed in 1999, including coastal counties north of Monterey and the San Francisco Bay Area. In addition to collecting maps from field experts, data were collected using a hand-held Trimble GeoExplorer II GPS (Global Positioning System) unit (Trimble, Sunnyvale, CA) with an overall corrected accuracy of 1 to 3 m. A series of sites originally mapped in 1995 by Cal-IPC were re-surveyed for Cape ivy in 2000, with 95% of these locations still supporting the invasive species.

Several individuals and organizations provided large Cape ivy distribution data sets that were incorporated into our database. Most notable was an extensive set of maps provided by Golden Gate National Recreation Area (GGNRA) employees. These maps included data from Marin, San Francisco and San Mateo counties in the form of ArcView shapefiles. Electronic data were also provided for Pt. Reyes National Seashore by the National Park Service, Catalina Island by the Catalina Island Conservancy, and Contra Costa Co. by the Contra Costa Watershed Forum. The other data collected were on paper maps obtained from 12 sources ranging from Oregon to San Luis Obispo. These were digitized onto 1:100,000 scale topographic maps. Other mapping points were provided for a number of counties from Del Norte to San Diego.

All the spatial data were brought into a GIS (Geographic Information System). In 1999, MapInfo Professional 5.0 was used to create maps, as well as store and edit the data. The GPS data was exported from Pathfinder to a MapInfo format, and ArcView shapefiles were converted to MapInfo format and included in the GIS. Some of the data provided by GGNRA were polygon or line data and these were converted to point data for the final analysis.

In 2000, vegetative community types and stipulate or exstipulate morphological forms of Cape ivy were also recorded using GPS. The California Natural Diversity Data Base (CNDDB) (California Fish and Game, http://www.dfg.ca.gov/biogeodata/cnddb/) community type which classifies vegetation using a five-number land cover code was chosen for the mapping analysis, and field data was collected using the number code. From 2001 to 2004, data were collected with a Garmin eTrex Vista GPS (Garmin Ltd., Olathe, KS) with accuracy of 15 meters alone and <3 m with the Wide Area Augmentation System (WAAS) enabled. Waypoints collected with the eTrex Vista were converted to ArcView shapefiles with Waypoint+ version 1.8.03. After conversion, the data files were edited to contain attribute fields listed in Table 1. Maps presented here are in the Teale-Albers projection, geographic coordinate system NAD 1927.

GIS Analysis

BIOCLIM Raster Extraction. GIS analysis was performed with ArcView version 9.0 (ESRI, Redlands, CA) and the Spatial Analyst extension (version 9.0). Polygon data collected in the distribution mapping phase were converted to points and 1465 Cape ivy location points were used as the basis for GIS analysis. In order to determine the elevation and climate parameters associated with the distribution data set in California, the point data was joined with BIOCLIM raster datasets. The bioclimatic variables (BIOCLIM) raster layers were derived from WorldClim interpolated climate layers (http://www.worldclim.org/methods). The WorldClim climate layers contain precipitation records for 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations (Hijmans et al. 2004). WorldClim altitude was obtained from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Models (http://www2.jpl.nasa.gov/srtm/). Grids used in the analysis were at 30 seconds (1 km). A spatial join of Cape ivy point data and BIOCLIM rasters was accomplished with the ArcView Spatial Analyst "extract values to points" tool. For example, when the BIOCLIM annual precipitation raster data set was spatially joined to the Cape ivy point data a column with annual precipitation was generated in the attribute table. This was repeated for all the raster layers. Excel (Microsoft Corp., Redmond, WA) and JMP IN (version 5.1) (SAS Institute Inc., Cary, NC) were then used to determine the range and mean values for the raster layers.

CNDDB Sensitive Species Overlay. Overlay analysis was performed with the Cape ivy point data and the California Natural Diversity Database (CNDDB) sensitive species location data. The data are available within an application called RareFind, a Windows based program developed by the California Department of Fish

TABLE 1. ATTRIBUTES OF CAPE IVY USED IN FINAL MAPPING SHAPEFILES.

Field name	Description
SHAPE	all points
SITECODE	map identification point, using county abbreviation and number
COUNTY	county
GPS	true or false
VISITED	date of GPS
SURVEYOR	surveyor or source of data
ENTEREDBY	person digitized by
DATAFILE	name of rover file for GPS data or original shapefile name
SCI_NAME	*Delairea odorata*
COMMENT	source of data, location, directions, etc.
GPS CODE	waypoint code for eTrex Vista data
VEGTYPE	Holland (1986) numerical code used by CAGAP (Davis et al. 1998)
ST_NS	either stipulate (ST), exstipulate (ES) or both (STES)
VIABLE	viable seeds present, Yes or No
LAT	generated with the "add XY" tool in ArcView 9.0
LONG	generated with the "add XY" tool in ArcView 9.0

and Game, Sacramento, CA (http://www.dfg.ca.gov/biogeodata/cnddb/rarefind.asp) and designed to perform queries and produce reports. RareFind comes with GIS layers, which were used for this analysis (RareFind version 3.0.5 dated September 2, 2005). The CNDDB data consists of locations for sensitive plants, animals and natural communities as well as population data voluntarily submitted by field biologists. Sensitive species are defined as federally and state listed plants and animals, all species that are candidates for listing, all species of special concern and those species that are considered sensitive by government agencies and conservation organizations (http://www.dfg.ca.gov/whdab/pdfs/cnddbfaq.pdf). The data were then reviewed for accuracy and mapped by CNDDB personnel as "occurrences" at various levels of precision, from specific points to non-specific buffered polygons.

For the CNDDB GIS analysis, Cape ivy points were buffered out 100 m to represent the current extent of their direct or indirect influence on sensitive species locations. The "select by location" feature in ArcView was used to select the sensitive species occurrences, which overlapped with the 100 m buffered points. The selected polygons from the CNDDB data were then saved into a separate shapefile. Another file was created with Cape ivy points buffered out to 500 m, representing an estimate of future spread, while another shapefile with sensitive species occurrences was generated for comparison.

RESULTS AND DISCUSSION

Mapping

California and Oregon Cape Ivy Distribution. Cape ivy has been known to occur in California since 1892, yet many of the historic floras only mention it in passing and do not indicate it as a widespread weed (Munz 1974; Smith 1976; Beauchamp 1986; Junak et al. 1995). In the 1970's it was noted as "climbing on trees, mostly willows, along coastal streams," and "forming dense tangles in shaded canyons or on moist open slopes" (Hoover 1970; Howell 1970). Floras from the 1990's noted that it is common or invasive in coastal areas (Best et al. 1996; Matthews 1997). Surprisingly, as late as 1992 the Mendocino Flora states that it is "occasional but seldom collected" (Smith and Wheeler 1992). In fact, there are no voucher records of Cape ivy in Mendocino County in the Consortium of California Herbaria (http://ucjeps.berkeley.edu/consortium/) prior to 2001, despite it widespread occurrence there today.

Based on the field survey, Cape ivy occurs throughout all coastal counties of California, as well as the Channel Islands (Santa Rosa, Santa Cruz and Santa Catalina) and Curry Co., Oregon (Figs. 1–3). Furthermore, it was also found in most of the major river systems along the coast. Although the vast majority of Cape ivy infestations were found within a few kilometers of the coast, populations occurred 60 to 70 km inland in Contra Costa and Los Angeles counties.

Interestingly, in its native range in South Africa, nearly all collections of Cape ivy have been reported to be the stipulate form (Balciunas and Smith 2006; Robinson 2006). In California, however, the exstipulate form is far more commonly encountered than in its native range (Fig. 4). Although the exstipulate form is found throughout California, it is the primary morphological type in the northern extent of its range, including Curry Co., Oregon, and northern Humboldt Co., as well as the southern range of its distribution in Los Angeles and San Diego counties.

The stipulate forms were most widespread throughout the center of the range of the species, from Mendocino Co. to Santa Barbara Co.

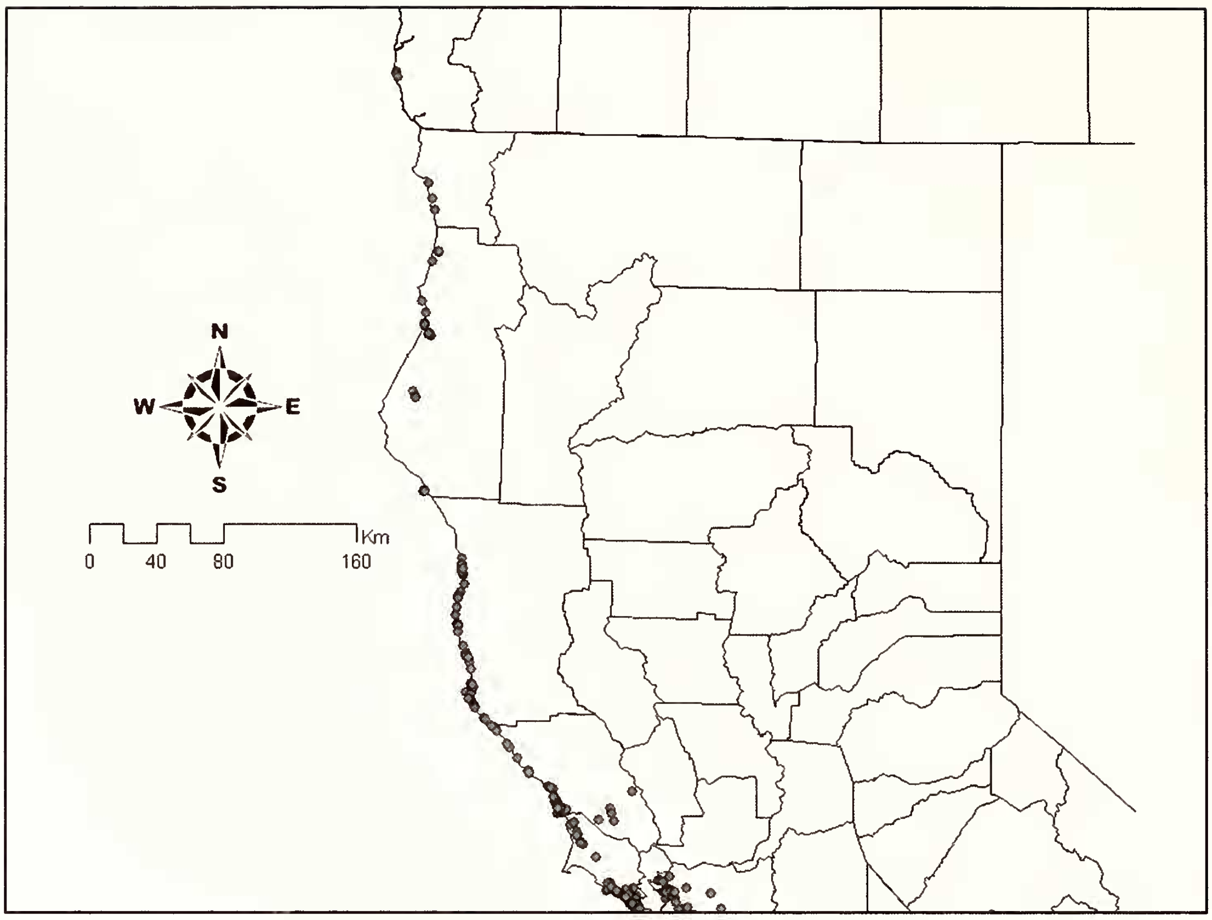

FIG. 1. Cape ivy locations in northern California and southern Oregon.

(Fig. 4). A combination of the two morphological forms was most common in heavily populated areas, particularly the San Francisco Bay region and San Luis Obispo Co.

GIS Analysis

The climate where Cape ivy grows in California can be broadly described as Mediterranean. Mediterranean climates are characterized by dry summers and an average of 25 to 100 cm annual rainfall concentrated during the mild winter months (Dallman 1998). Snow is infrequent except at higher elevations, and the amount of winter rain is highly variable from year to year.

BIOCLIM Raster Extraction. BIOCLIM Raster Extraction analysis indicates that Cape ivy in

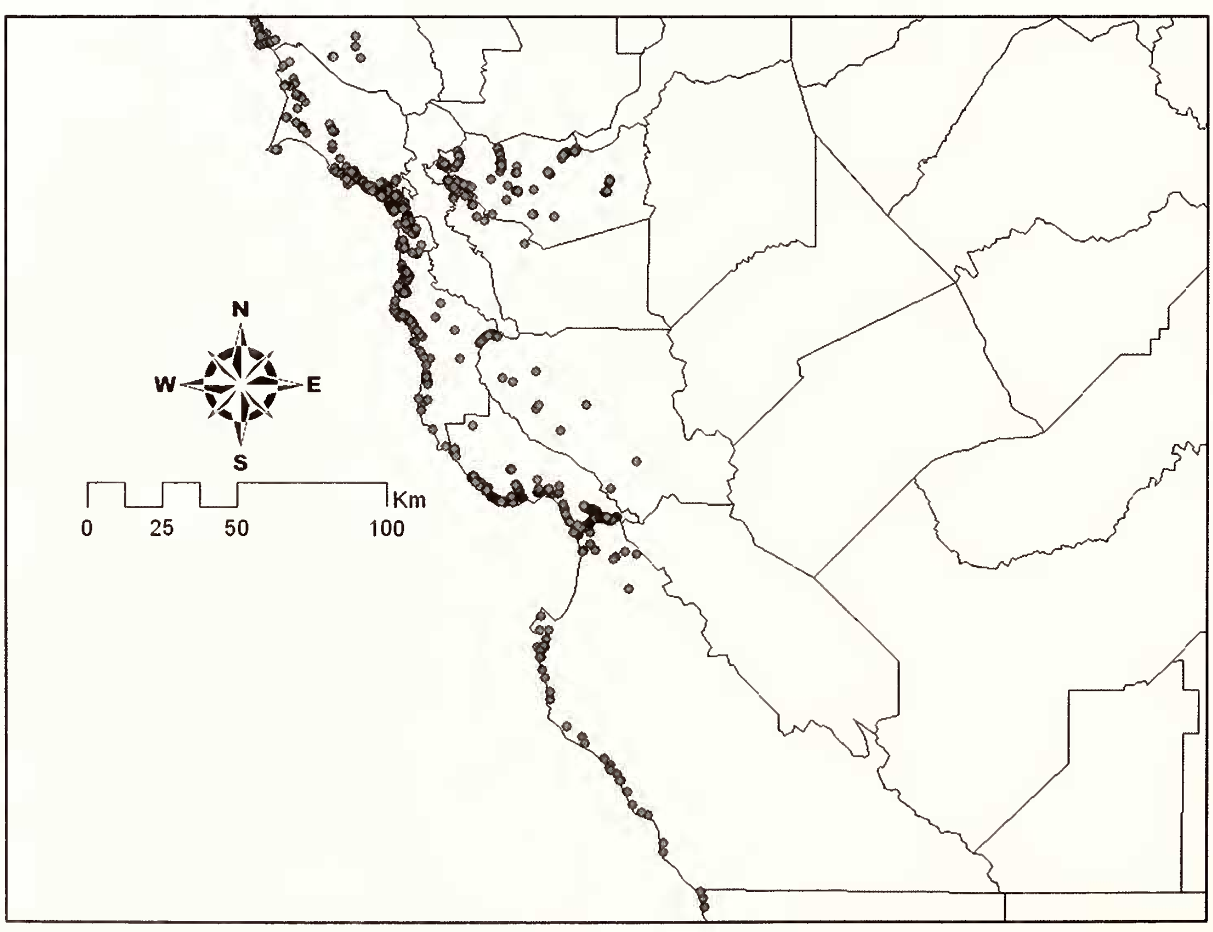

FIG. 2. Cape ivy locations in the San Francisco Bay Area and central California.

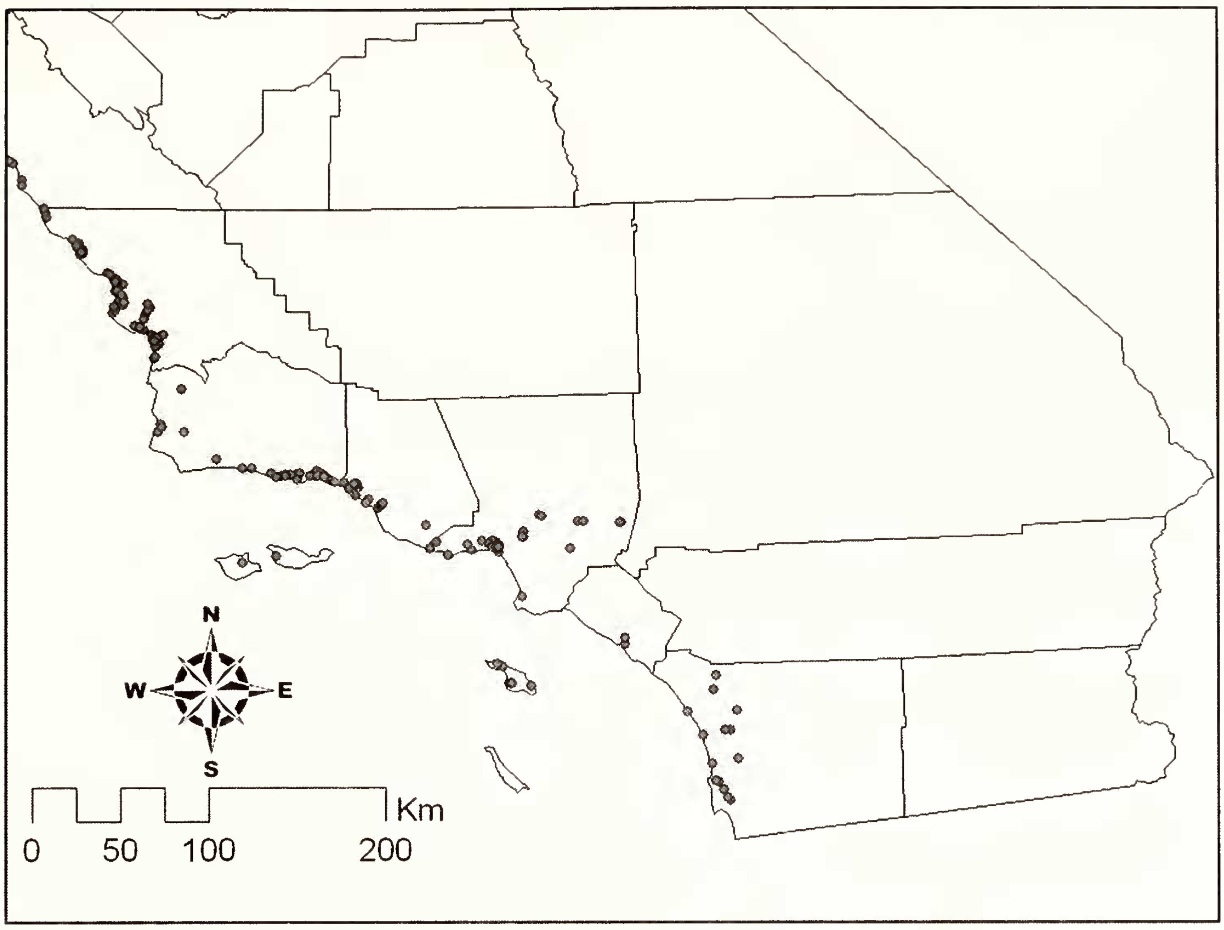

FIG. 3. Cape ivy locations in southern California.

California occurs at elevations between 0 and 891 meters, annual mean temperatures between 10.5 and 17.7°C, and in areas with annual precipitation ranging between 232 and 2270 mm (Table 2). Examining the maximum temperature of the warmest month and the minimum temperature of the coldest month, the results suggest that Cape ivy can tolerate temperatures between 1.8 and 31.8°C.

Vegetation community types. From the field GPS data, Cape ivy was most often observed in urban or agricultural areas (Table 3). This was expected, as Cape ivy was introduced as a horticultural plant and many of the surveys were conducted in easily accessible urban areas. Invasive populations were also common in riparian and non-native *Eucalyptus* forests, oak woodlands, and coastal scrub communities. In contrast, only two Cape ivy populations were observed in coniferous forests and only one occurred in a salt marsh.

CNDDB sensitive species overlay. Using either a 100 or 500 m buffer, we determined the number of CNDDB sensitive species overlapping with community types known to be invaded by (Table 4). For example, 163 sensitive vascular plants were expected to overlap with predicted Cape ivy sites using a 100 m buffer around the infested location, whereas 211 sensitive species overlapped the expected Cape ivy infested areas as predicted by the 500 m buffer. Each Cape ivy infestation was predicted to overlap with a mean of 2.2 sensitive vascular plant species at a 100 m buffer, and 2.8 sensitive plants at a 500 m buffer.

The number of predicted sensitive species occurrences per infestation was relatively small using the 100 and 500 m buffer areas. In all cases, except non-vascular plants, the number of overlapped occurrences and the mean number of sensitive species occurrences in Cape ivy sites increased as the buffer size increased. Although most groups only had a few predicted overlaps between sensitive species and Cape ivy infestations, some species within these groups frequently overlapped in their predicted occurrences. Species that had a significant overlap in occurrences using a 100 or 500 m buffer are listed in Table 5. With the 100 m buffer, only animals overlapped with Cape ivy infestations, while the 500 m buffer overlapped both animals and plants. The percent potential overlap between each sensitive species and Cape ivy was calculated by dividing the number of predicted overlapping occurrences (100 and 500 m buffer areas) by the number of total sensitive plant occurrences. Among the sensitive vascular plant species, several showed >40% potential overlap, including the San Francisco Bay spineflower (*Chorizanthe cuspidata* S. Watson var. *cuspidata*), Franciscan thistle (*Cirsium andrewsii* (A. Gray) Jeps.), San Francisco gumplant (*Grindelia hirsutula* Hook & Arn. var. *maritima* (Greene) M. A. Lane), perennial goldfields (*Lasthenia macrantha* (A. Gray) Greene ssp. *macrantha*) and marsh microseris (*Microseris paludosa* (Greene) J. T. Howell). These species are expected to be greatly impacted by the expansion of Cape ivy infestations.

There was also a considerable overlap between predicted Cape ivy infestations and steelhead

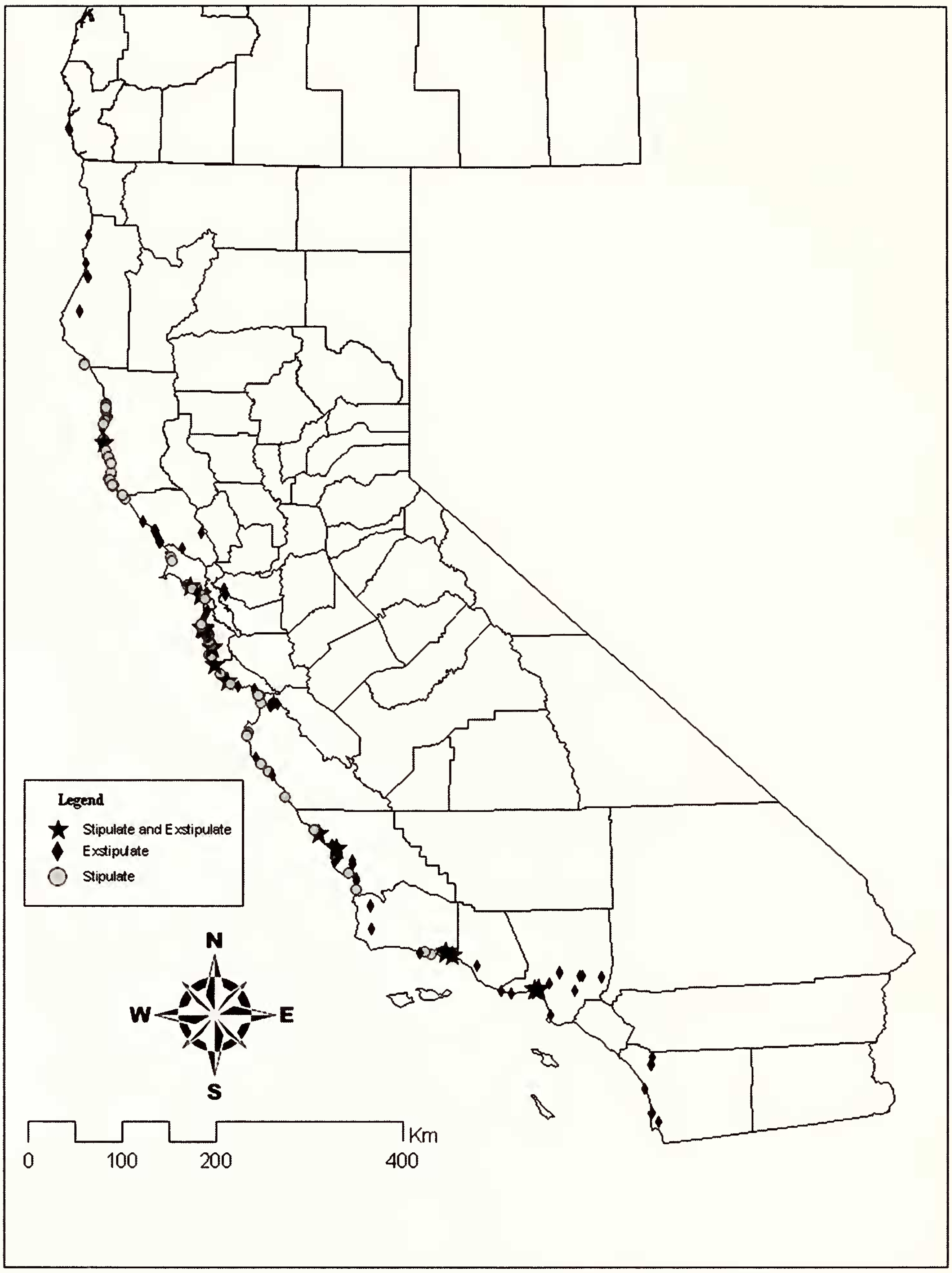

FIG. 4. Distribution of stipulate and exstipulate forms of Cape ivy, including locations where both forms co-occur.

salmon (*Oncorhynchus mykiss*) populations (Table 5). Using a 500 m buffer, the percentage overlap between Cape ivy and streams supporting steelhead ranged between 42 and 50%. Although no published studies have been reported on the toxicity of Cape ivy to fish, some evidence (C. Bossard unpublished data) suggests that Cape ivy is toxic to the golden shiner (*Notemigonus*

TABLE 2. CAPE IVY DISTRIBUTION ATTRIBUTES EXTRACTED FROM BIOCLIM RASTER DATA (n = 932 EXCEPT WHERE NOTED). BIOCLIM link: http://www.worldclim.org/methods. [1] Quarter = three consecutive months.

BIOCLIM variable	Mean ± SE	Minimum value	Maximum value
Elevation (m) n = 1057	66.7	0	891
Annual mean temperature (°C)	13.3 ± 0.04	10.5	17.7
Maximum temperature of warmest month (°C)	23.2 ± 0.08	19.5	31.8
Minimum temperature of coldest month (°C)	4.6 ± 0.03	1.8	7.9
Mean annual precipitation (mm)	826 ± 11	232	2270
Precipitation in wettest quarter[1] (mm)	369 ± 4.5	101	950
Precipitation in driest quarter (mm)	8.2 ± 0.3	0	72

TABLE 3. RECORDED COMMUNITY TYPES WHERE CAPE IVY WAS OBSERVED, BASED ON GPS DATA. [1] Community codes from Holland (1986).

CNDDB community type code[1]	General type	Specific type	Number of observations from field data
11100	urban or agriculture	urban or built-up land	33
11300	non-native forest	*Eucalyptus*	11
21310	coastal scrub	northern dune scrub	1
31100	coastal scrub	northern coastal bluff scrub	12
32100	coastal scrub	northern (Franciscan) coastal scrub	12
32200	coastal scrub	central (Lucian) coastal scrub	5
32300	coastal scrub	venturan coastal sage scrub	3
52120	salt marsh	southern coastal salt marsh	1
61110	riparian forest	northern coast black cottonwood riparian forest	1
61130	riparian forest	red alder riparian forest	23
61210	riparian forest	central coast cottonwood-sycamore riparian forest	2
61220	riparian forest	central coast live oak riparian forest	1
61230	riparian forest	central coast arroyo willow riparian forest	28
61310	riparian forest	southern coast live oak riparian forest	2
61320	riparian forest	southern arroyo willow riparian forest	6
62100	riparian forest	sycamore alluvial woodland	1
62400	riparian forest	southern sycamore-alder riparian woodland	4
63100	riparian forest	northern coast riparian scrub	21
63320	riparian scrub	southern willow scrub	1
71160	oak woodland	coast live oak woodland	13
82320	conifer forest	upland redwood forest	1
83120	conifer forest	Bishop pine forest	1

crysoleucus) and crushed Cape ivy leaves caused mortality in mosquito fish (*Gambusia affinis*) within three days (J. Balciunas unpublished data). However, the latter study used crushed leaves of Cape ivy which may not represent exposure typically found in nature. Because other related species (i.e., *Senecio*) are known to contain pyrrolizidine alkaloids (Manske 1936; Adams and Gianturco 1956; Stelljes et al. 1991; Catalano et al. 1996), which can cause liver damage in humans, animals, and fish (Hendricks et al. 1981), the potential toxic effect of Cape ivy on steelhead populations is of concern because of its close proximity to water and its high density in many infested areas.

Of the invertebrates co-occurring within predicted Cape ivy populations, only one species, Monarch butterfly (*Danus plexippus*), showed any significant overlap, with 13 and 25% of its occurrences within the 100 and 500 m buffers, respectively (Table 5). The potential for Cape ivy alkaloids to affect the Monarch butterfly has been studied indirectly, but with no conclusions as to the potential impact. Monarch butterflies were found to have accumulated pyrrolizidine alkaloid after over-wintering in Cape ivy infested areas (Stelljes and Seiber 1990). The butterflies accumulate pyrrolizidine alkaloids after using Cape ivy as a nectar source. Although this was postulated to provide a chemical defense mech-

TABLE 4. CNDDB SENSITIVE SPECIES OVERLAP WITH CAPE IVY SUMMARIZED BY GROUP CLASSIFICATION.

Group classification	Species overlapping with Cape ivy at 100 m buffer	Mean number of species per occurrence at 100 m buffer ± SE	Species overlapping with Cape ivy at 500 m buffer	Mean number of species per occurrence at 500 m buffer ± SE
Natural communities	24	2.1 ± 0.3	35	2.4 ± 0.4
Non-vascular plants	8	1 ?	8	1.5 ± 0.3
Vascular plants	163	2.2 ± 0.1	211	2.8 ± 0.2
Invertebrates	32	3.5 ± 1.3	37	5.1 ± 2.2
Fish	7	9.3 ± 4.6	9	10.0 ± 5.0
Reptiles	7	3.4 ± 1.1	9	4.8 ± 1.5
Amphibians	4	4.8 ± 2.8	8	6.9 ± 4.6
Birds	20	2.6 ± 0.6	28	3.3 ± 0.8
Mammals	13	2.2 ± 0.5	18	2.8 ± 0.6

TABLE 5. CNDDB SENSITIVE SPECIES LOCATIONS AND PREDICTED OVERLAP OF CAPE IVY AND SENSITIVE SPECIES AT EITHER 100 OR 500 M BUFFERS. [1]ESU = evolutionarily significant unit.

Scientific name	Common name	Number of occurrences tracked by CNDDB	Number (percent) of occurrences overlapping with predicted Cape ivy populations	
			Using 100 m buffer	Using 500 m buffer
Animals				
Rana draytonii	California red-legged frog	831	13 (2)	39 (5)
Charadrius alexandrinus nivosus	western snowy plover	109	13 (12)	22 (20)
Eucyclogobius newberryi	tidewater goby	112	28 (25)	41 (37)
Oncorhynchus mykiss irideus	steelhead—central California coast ESU[1]	28	13 (46)	14 (50)
Oncorhynchus mykiss irideus	steelhead—south/central California coast ESU	27	9 (33)	12 (44)
Oncorhynchus mykiss irideus	southern steelhead—southern California ESU	12	4 (33)	5 (42)
Danaus plexippus	monarch butterfly	335	43 (13)	83 (25)
Arborinus pomo	Sonoma tree vole	208	—	10 (5)
Actinemys marmorata	western pond turtle	302	—	11 (4)
Actinemys marmorata pallida	southwestern pond turtle	308	—	13 (4)
Vascular plants				
Campanula californica (Kellogg) A. Heller	swamp harebell	100	—	10 (10)
Castilleja mendocinensis (Eastw.) Pennell	Mendocino coast indian paintbrush	42	—	12 (29)
Chorizanthe cuspidata S. Watson var. *cuspidata*	San Francisco Bay spineflower	20	—	10 (50)
Cirsium andrewsii (A. Gray) Jeps.	Franciscan thistle	27	—	11 (41)
Grindelia hirsutula Hook & Arn. var. *maritima* (Greene) M. A. Lane	San Francisco gumplant	15	—	11 (73)
Lasthenia californica subsp. DC. ex Lindl. *macrantha* (A. Gray) R. Chan	perennial goldfields	32	—	13 (41)
Microseris paludosa (Greene) J. T. Howell	marsh microseris	22	—	10 (46)

anism against potential predators, it is also possible that these alkaloids may have a direct negative affect on the butterflies.

CONCLUSIONS

This updated state-wide mapping of Cape ivy populations should aid in regional weed planning and in identifying areas of greatest potential invasion. Cape ivy was present in seven different broad plant community types. This is contrary to the common assumption that Cape ivy is primarily or even exclusively a riparian invasive (Hoover 1970; Smith 1976; Beauchamp 1986; Barbour and Billings 2000). State-wide trends in distribution of the two morphological forms indicate that exstipulate types occur more frequently at the northern and southern range of its distribution, while stipulate types are more frequent in the center of its distribution range, extending from southern Humboldt Co. to Los Angeles Co. Only 21 locations were found that supported both stipulate and exstipulate plants and these were most often in urbanized coastal areas.

Another important aspect of this study was to evaluate the potential threat of Cape ivy on CNDDB sensitive species known to occur in or around invaded plant community types. Although the threat to biodiversity was not measured directly, the CNDDB dataset served as a surrogate for native species biodiversity. This analysis suggests that six plants of limited distribution and nearly 50% of steelhead streams are threatened by the potential expansion of Cape ivy populations. This is of great concern to ecosystem integrity of these sensitive sites and should result in prioritization of effective Cape ivy management programs in California and southern Oregon.

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